OCR
RECOGNISING ACHIEVEMENT

Wednesday 23 January 2013 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

INSERT

G411690113

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- This Insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

- Do not send this Insert for marking; it should be retained in the centre or recycled. Please contact OCR Copyright should you wish to re-use this document.

The laser – a surgeon's best friend

Since its invention and development over fifty years ago, the laser has found numerous applications in a wide range of contexts, including medicine. Although many different materials are used to make them, all lasers operate in essentially the same way. Electrons in the atoms of the selected material – called the gain medium – are excited to a higher energy level in such a way that the number of atoms with this energy E_2 is more than the number with a lower energy E_1. This is called a population inversion: normally the number of atoms in the excited state is much smaller than the number in the lower energy state. If a photon of energy $hf = E_2 - E_1$ passes through the gain medium an electron in the higher energy level can be stimulated to fall down to the lower level. Another photon is emitted when this happens – see Fig. 1. The emitted photon will have exactly the same direction, frequency and phase as the photon which stimulated its production in the first place: the two photons will be coherent. This process of stimulated emission was predicted by Einstein in 1917.

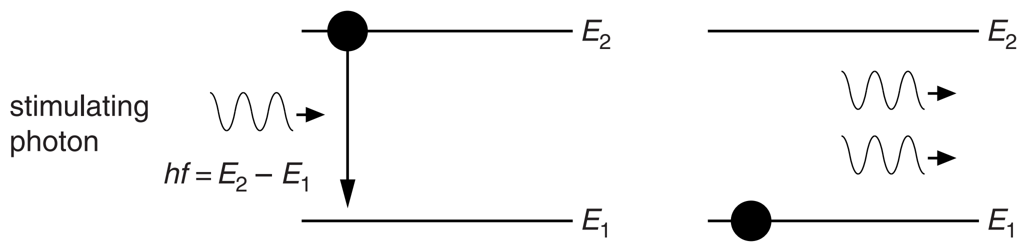

Fig. 1: stimulated emission

To make a laser, the gain medium is placed inside a 'cavity' made with two mirrors facing each other, Fig. 2. Photons travelling in a direction parallel to the cavity axis bounce back and forth within the cavity causing stimulated emission, increasing the number of photons all the time. A standing wave forms within the cavity which has a fixed length, d. One of the mirrors is a partial reflector so that light from the standing wave can leak through it and form the laser output. What emerges is a monochromatic, coherent and powerful beam of radiation.

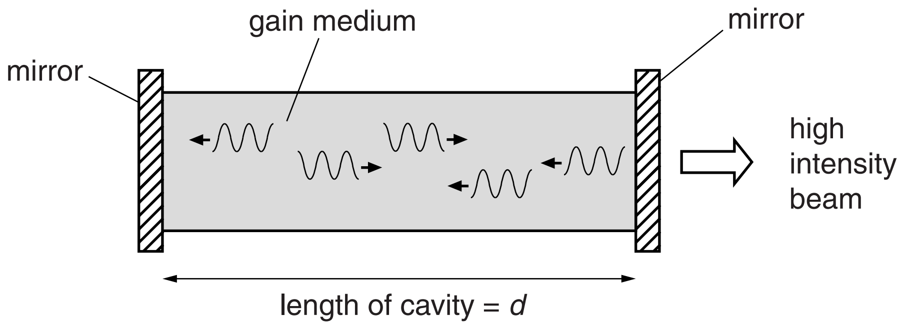

Fig. 2: the radiation reflects back and forth in the gain medium cavity, building up a standing wave

Laser energy

In some lasers, the population inversion is maintained by providing the energy needed to raise electrons to the higher levels in a series of optical or electrical pulses. Thus the photons also emerge in regular bursts and this is called a pulsed laser. In others, the population inversion is maintained continuously and the laser radiation emerges as a steady beam – these are continuous wave (cw) lasers. The amount of energy deposited into the target from a laser depends upon the energy of the photons, the rate at which the photons arrive and the amount of time over which they are arriving.

Lasers in Surgery

The use to which a laser is put depends mostly on the wavelength of the radiation it emits. Human tissue responds in different ways to different wavelengths of the electromagnetic spectrum. Soft tissue is made of many different substances and each absorbs light in its own way. Three substances in human skin and the soft tissue immediately beneath it are melanin (responsible for skin colouring), blood and water. The absorption by water of different wavelengths is shown in Fig. 3, in which the absorption coefficient, μ, is defined as the reciprocal of the depth within which the intensity falls by a factor of 1/e (about 0.37). For example, an absorption coefficient of $0.1\,\text{cm}^{-1}$ indicates that the intensity I of the radiation will have been reduced to about $0.37\,I$ within 10 cm. The absorption can be represented by the equation $I = I_0\, e^{-\mu x}$, where I_0 is the incident laser intensity and x is the depth in cm.

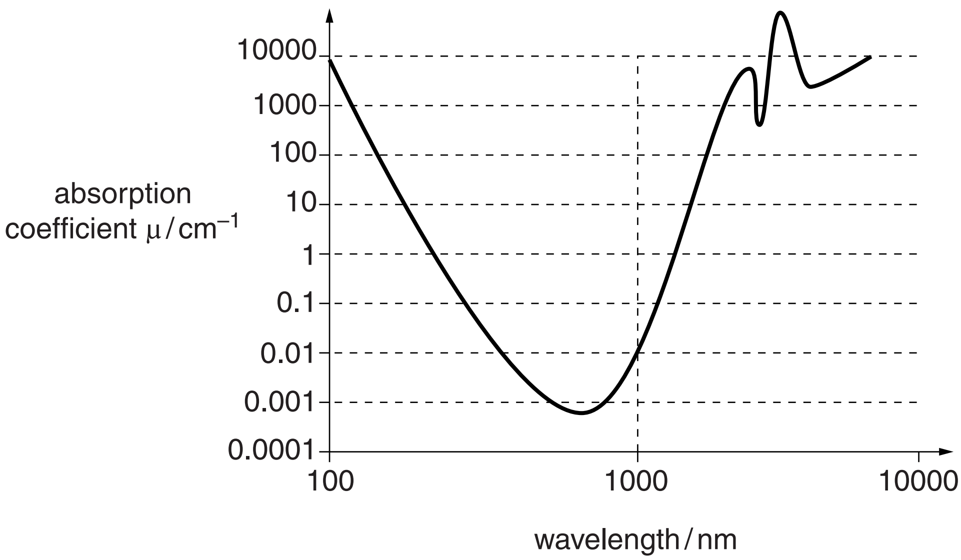

Fig. 3: different wavelengths of laser radiation are absorbed by different amounts by water, one of the main components (70%) of soft tissue

The interaction of laser radiation with such biological tissue occurs under the broad headings of thermal, mechanical, and chemical and the precise type of laser used in a surgical procedure will depend upon the particular type of surgery required.

Thermal effects

For surgical procedures, tissue cells need to be broken up in a controlled fashion but without excessive heating taking place as this could cause damage to surrounding tissue. Heating tissue to about 60 °C causes what is known as coagulation, a process which causes it to shrink. This can be very useful, for example, for sealing blood vessels and preventing bleeding. A very narrow beam of powerful laser light can thus be used as a "bloodless scalpel". At higher temperatures (greater than 100 °C), the water in tissue cells boils causing destruction of cells as the vapourised water expands, a process known as ablation. Carbon dioxide (CO_2) lasers, which can be used in pulsed or continuous wave mode, have a wide range of applications, including straightforward surgical techniques involving coagulation. The CO_2 laser radiation is invisible, so the visible red light from a helium-neon (He-Ne) laser is used to provide a guide beam.

Mechanical effects

When particularly powerful laser beams are used, energy can be given to the tissue in a very short space of time. A pulse of high energy photons delivered in a nanosecond or so can break apart molecules without much heating taking place. This is called optical breakdown and leads to the production of short-lived “micro-plasmas”, tiny regions of ionisation with a density of liberated electrons as high as 10^{21} per cubic centimetre. The rapid expansion of the plasma leads to mechanical damage to the surrounding medium, although this remains a tiny region. Because it is a non-thermal effect and cell destruction is highly localised this can be used to remove tissue on a very delicate scale, for example in the eye. One type of laser used for this work is the pulsed neodymium:YAG (Nd:YAG) laser in which the gain medium is an yttrium-aluminium-garnet crystal doped with the element neodymium. Its radiation is very penetrating and, when administered in short pulses, is used for eye surgery (Fig. 4).

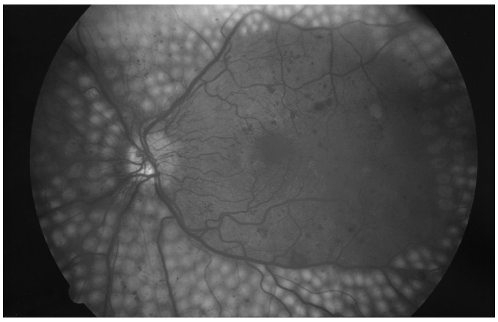

Fig. 4: neodymium:YAG lasers can be used to make repairs to tiny localised areas in the retina of the eye

Photochemical reactions

The behaviour of some chemicals can be affected very profoundly by light and other parts of the electromagnetic spectrum. Certain drugs, for example, become very active when illuminated with short-wavelength visible light. If the chemical is reacting in something not far below the skin, then the laser can be shone directly onto the skin surface. However, to illuminate deeper regions, the light has to be directed using optical fibres. For this work, metal-vapour lasers are used, in which the gain medium consists of a mixture of neon and a vapourised metal, often gold.

The future

By applying the same principles to different materials for more than fifty years, lasers have found uses in a very wide range of applications with many, such as DVD players, bar code readers and telecommunications, encountered every day. Current developments of solid state lasers have started a new era in laser technology, though the basic principle remains the same. As higher-powered semiconductor lasers become a reality, no doubt the world of medicine and surgery will continue to benefit from this truly cutting-edge technology.

END OF ARTICLE

BLANK PAGE

BLANK PAGE

BLANK PAGE